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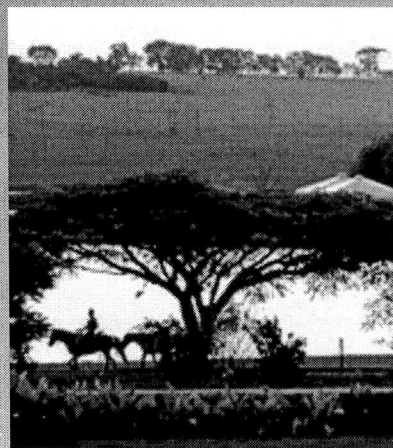


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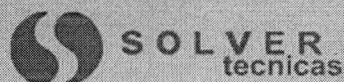




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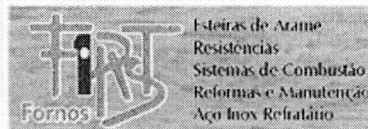
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Rapid Stress Relief and Tempering: process description .

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ABSTRACT

Stress relief and tempering are important processes but these processes are still conducted much as they have been for over 50 years. However, advanced Pyromaitre's equipment designs are available which permit these processes to be conducted in a fraction of time that was formerly possible producing substantial improvements in productivity, cost, and energy saving.

In this paper, "rapid" stress relief and tempering processing will be discussed along with the equipment used accomplish these benefits. In addition the use of a simulation program for equipment selection and use will be described.

Key-words: Heat treatment, temper, equipment

INTRODUCTION

Rapid heating is defined as "any heating method that accelerates conventional furnace heating" [1]. Heat transfer rates of up to thirty (30) times those achieved in conventional convection furnaces are possible [2]. In the past rapid heating technology has been applied primarily to the forging industry where steel is heated to 1000 – 1250°C (1830 – 2280°F) and it is much less commonly encountered in the heat treating industry.

Although rapid heating is enjoying increasing use in for stress relieving, the use of rapid heating technology is still in its infancy for tempering processes. In this paper a brief overview of stress relieving and tempering will be provided; high-speed convection and temperature uniformity will be addressed, use of a laboratory batch

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oven to model in-line continuous oven heating (and cooling) will be discussed and finally selected examples will be provided.

DISCUSSION

The Stress Relieving Process

Stress relieving is typically used to remove residual stresses which have accumulated from prior manufacturing processes. Stress relief is performed by heating to a temperature below A_{c1} and holding at that temperature for the required time to achieve the desired reduction in residual stresses and then the steel is cooled at a rate sufficiently slow to avoid formation of excessive thermal stresses. No microstructural changes occur during stress relief processing. Nayar recommends heating to [3]:

550-650°C for unalloyed and low-alloy steels;

600-700°C for hot-work and high-speed tool steels.

These temperatures are above the recrystallization temperatures of these types of steels. Little or no stress relief occurs at temperatures $< 260^{\circ}\text{C}$ and approximately 90% of the stress is relieved at 540°C . The maximum temperature for stress relief is limited to 30°C below the tempering temperature used after quenching [4]. Stress relieving results in a significant reduction of yield strength in addition to reducing the residual stresses to some "safe" value and crack-sensitive materials. Typically, stress-relieving times for specific alloys are obtained from standards such as those listed in Table 1 [5-7]. The stress-relieving times shown in Table I were developed for conventional convection heated batch oven. With rapid stress-relieving technology the total stress relieving time for 16 mm diameter CrSi wire can be reduced to 10 min. or less.

Table1

Stress Relief Temperatures and Times for Wire

Material	Specifications	Temperature (F)	Time (minutes)
Music Wire	ASTM A 228	450	30
Music Wire–tin-coated	ASTM A 228	300	30
Music Wire Cadmium-Zinc Coated	ASTM A 228	400	30
Music Wire	AMS 5112	540	60
O.T.M.B.	ASTM A 229	450	30
H.D.M.B. Class I or II	ASTM A 227	450	30
High Tensile Hard Draw	ASTM A 679	450	30
Galvanized M.B. Class I or II	ASTM A 674	450	30
Chrome-Silicon	SAE J157 or ASTM A 401	700	60
Chrome-Silicon (Lifens)	SAE J157	725	60
Chrome-Vanadium	ASTM A 231	700	60
Stainless Steel 301	----	650	30
Stainless Steel 302	AMS 5688	650	30
Stainless Steel 304	ASTM A 313	650	30
Stainless Steel 316	ASTM A 313	600	60
17-7 PH	AMS 5678	900	60
Phosphorous Bronze Grade A	ASTM B 159	375	30
Hasteloy C	----	500	30
Monel 400	----	625	60
Inconel 600	----	850	90
Inconel X 700 Spring Temper	AMS 5699	1200	240
Inconel X 750 /1 Temper	AMS 5698	----	----
Brass Wire	ASTM B 134	375	30
Berilium-Copper	ASTM B 134 or ASTM B 197	600	120
Blue-Temper	N/A	450	30

Among others, an expression used in evaluating the stress relief of spring steels is the Larson-Miller equation [5-8]:

$$P = T (\log t + 20) / 1000$$

Software (Pyromaitre's Pyrograph) has been developed which has utilized the use of the Larson-Miller equation to model production heating requirements for high-speed stress-relieving oven selection. A typical example of the output is shown in Figure 1.

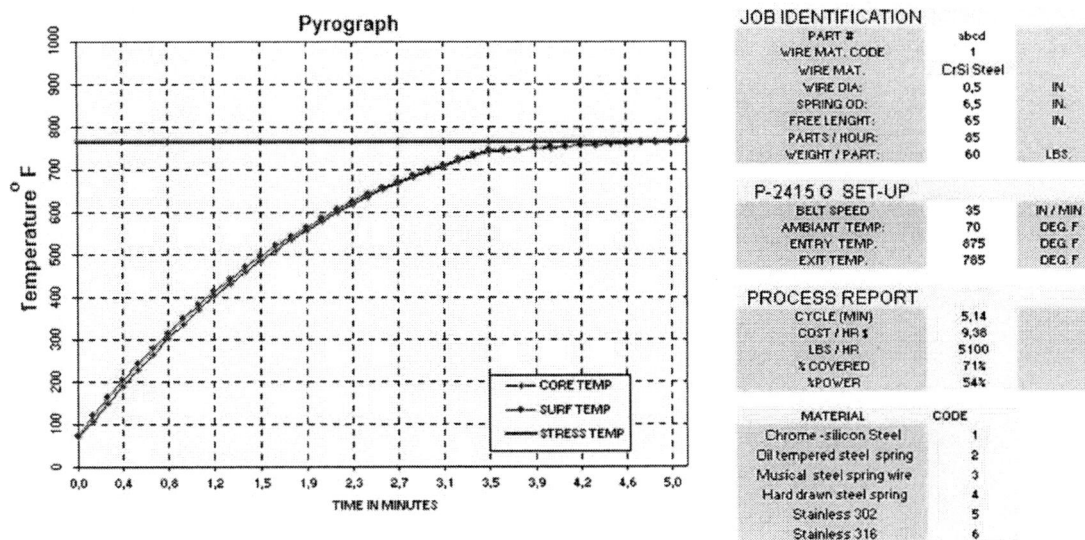


Figure 1 – Illustration of the pyrograph image showing both the input parameter menu and the graphical output.

Tempering

When steel is hardened, the as-quenched martensite is not only very hard but also brittle. Tempering, also known as “drawing”, is the thermal treatment of hardened and normalized steels to obtain the desired mechanical properties which include: improved toughness and ductility, lower hardness and improved dimensional stability. During tempering, microstructure modifications (carbide decomposition and martensite alterations) allow hardness to decrease to the desired level. The extent of the tempering effect is determined by the temperature and time of the process [9,10].

The tempering process may be conducted at any temperature up to the lower critical temperature (A_{c1}). Figure 2 illustrates the effect of carbon content and

tempering temperature on hardness of carbon steels [10]. The specific tempering conditions that are selected are dependant on the desired strength and toughness.

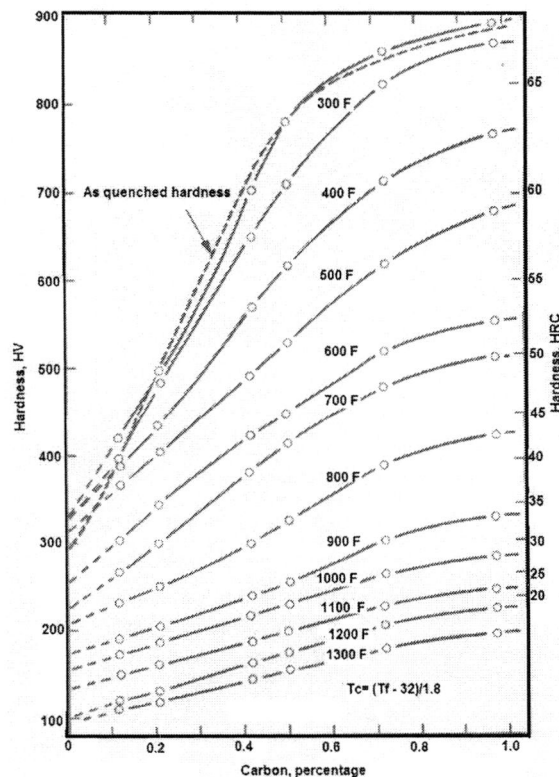


Figure 2 - Correlation of carbon content of martensite and hardness of different Fe-C alloys at different tempering temperatures.

Typically, tempering times are a minimum of approximately one hour. Thelning has reported a “rule of thumb” of 1-2 hours/inch of section thickness after the load has reached a preset temperature [4]. After heating, the steel is cooled to room temperature in still air. The recommended tempering conditions, in addition to recommended heat treating cycles, for a wide range of carbon and alloy steels is provided in SAE AMS 2759.

Tempering times and temperatures may also be calculated by various methods. One of the more common methods is to use the Larsen Miller equation discussed above. The Larsen-Miller equation, although originally developed for prediction of creep data, has been used successfully for predicting the tempering effect of medium/high alloy steels [11].

High Speed Convection

Tempering may be performed in convection furnaces, salt baths or even by immersion in molten metal. Among these, convection furnaces are the most common and it is important that they be equipped with fans and/or blowers to provide for uniform heat transfer when heating the load. Typically, convection tempering furnaces are designed for use within 150°C - 750°C.

One of the most important and critical deficiencies of most conventional stress-relieving and tempering ovens is the actual temperature non-uniformity of the material being heated. This is illustrated in Figure 3 where it is shown that the actual temperature of the part depends on its placement in the basket in the oven.

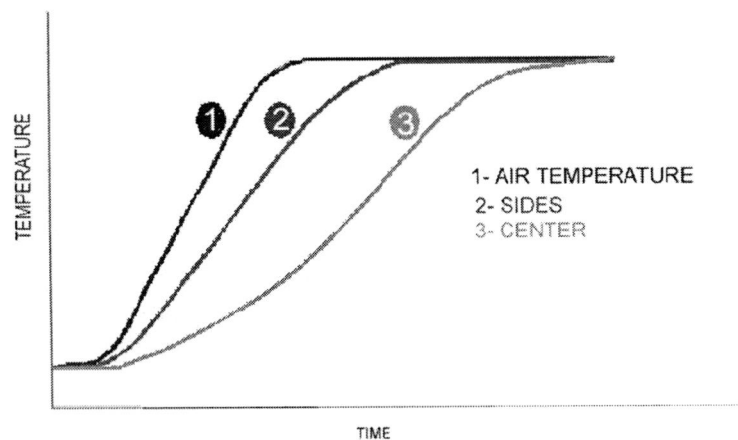


Figure 3 – Illustration of temperature non-uniformity typically present in conventional batch ovens.

A high-precision oven requires not only uniform temperature but uniform heat transfer. Rapid heat transfer is achieved by the use of turbines. However, this is not sufficient for uniform heat transfer which is achieved by the number of turbines used and their position, the shape of the heating chamber, and placement of the component on the belt to optimize surrounding air flow. Therefore, both the heating velocity and temperature uniformity of the part is optimized in the Pyro systems.

It is important to note that optimal stress relief for a given material is not a fixed value of one specific time and one specific temperature as suggested in Table 1. This is illustrated by x-ray diffraction data shown in Figures 4a and 4b [5-7]. These data show that five (5) minutes at 800°F is equivalent to 770°F using a Pyro high-speed stress relief oven. Also ten (10) minutes at 770°F in the same Pyro high-speed

stress-relieving oven is equivalent to 25 minutes in a conventional batch oven at the same temperature.

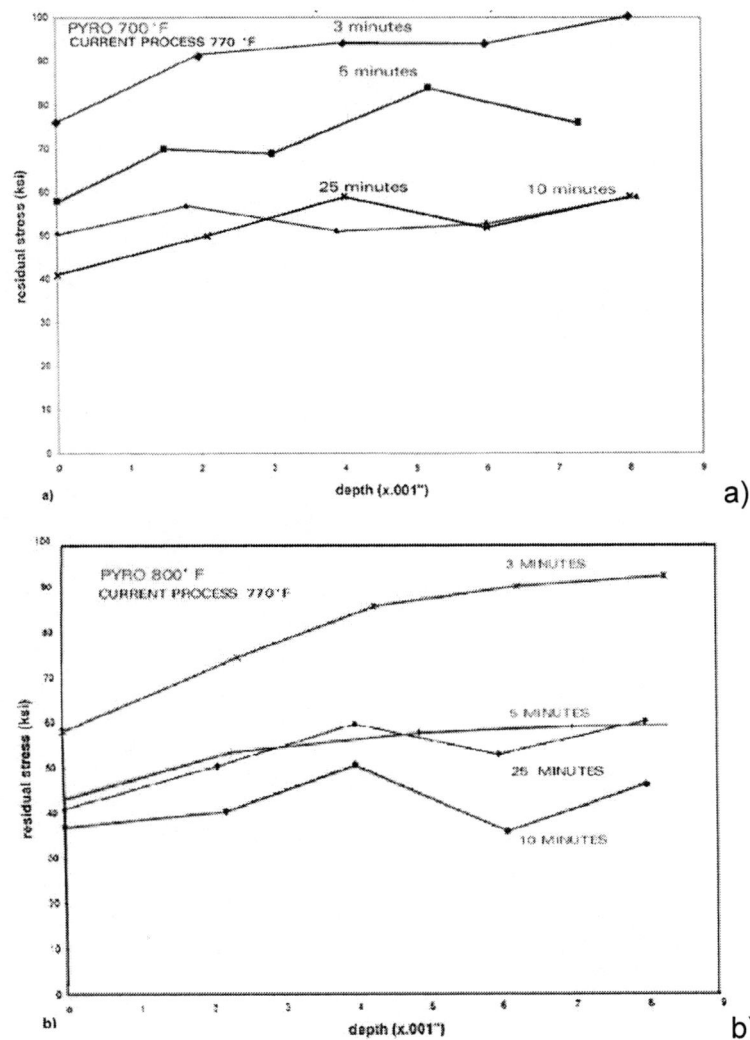


Figure 4 – Residual stress relief: a.) experiment conducted at 800° and b.) experiment conducted at 770°F.

Batch Oven for Continuous Process Simulation

It is typical practice to develop stress-relieving and tempering processes in the laboratory using a conventional batch convection oven. However, it is not unusual to obtain relatively poor correlation between the two ovens. There are a number of reasons for this. One is that it is not sufficient to model the actual process temperature but the heat up and cold down processes are vitally important as well. Recently, a high-speed convection batch oven (Pyro Try-Out Oven) has been

developed which exhibits unusual and outstanding temperature tolerance of $\pm 3^{\circ}\text{C}$ throughout the heating zone. In addition, the actual desired heat-up and cool down process can be programmed as well. Therefore, any in-line stress-relieving process using any oven and any size can be readily simulated using the Pyro Try-Out Oven. An illustration of heating and cooling curves attainable using this oven are illustrated in Figure 5.

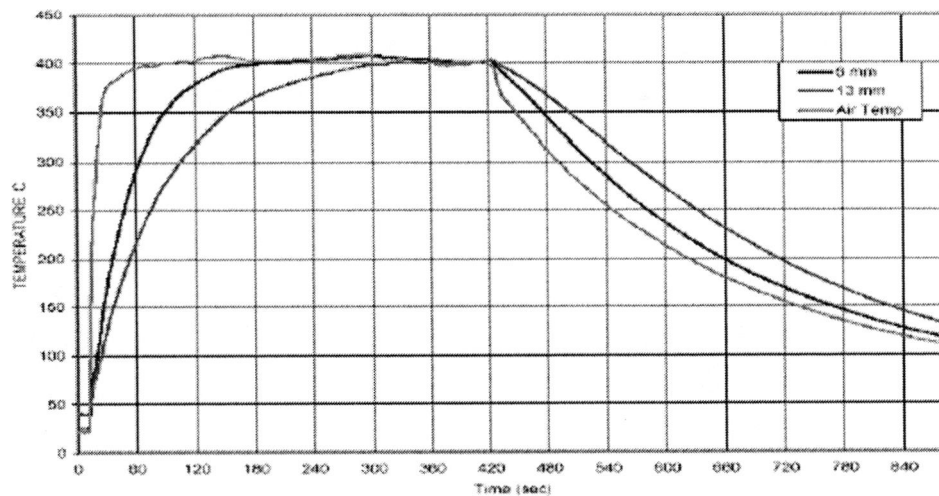


Figure 5 – Illustration of typical heating and cooling curves attainable with a Pyro Try-Out Oven.

Selected Example of Rapid Stress Relieving and Tempering

A comparison of the high-speed stress relieving process (7 min in a Pyro High-Speed Stress-Relief Oven) and conventional stress relief (35 min.) for car engine valve springs has been studied. In both cases, the stress relief temperature was 800°F. The tensile strength for the high-speed process was 275.5 Ksi versus 275.9 Ksi. The as-received wire samples exhibited an average tensile strength of 275.9 Ksi. The average hardness was essentially the same where the average HRC for rapid stress relief was 50.7 vs 50.8 for the conventional process and the average microhardness of the high-speed process was 0.6 HRC higher than the conventional process.

Ten valve springs from each process were fatigue tested for 50 million cycles. At the end of the test, the number of failures for each stress relieving process was equal to two (2) each. Load losses were measured at two heights. Load 1 was measured at 1.880 inches and load 2 was measured at 1.200 inches. The results of

these tests are summarized in Table 3. Based on failure and load loss results, it was concluded that the fatigue life of the valve springs produced by both the high-speed stress-relief process was a good or better than those produced by the conventional process. Today, car engine valve springs are now commonly stress relieved using a high-speed stress relieving process (using a Pyro oven).

Table 3
Load Loss Results for Automotive Valve Springs

Stress Relief Process	First Load Height (1.880 in.)	Second Load Height (1.200 in.)
Conventional Batch Oven	3.90%	1.80%
High-Speed Stress Relief Pyro Oven	1.90%	1.70%

X-Ray diffraction measurement comparison was made on automotive tension belt springs. The results shown in Figure 6 illustrate that essentially the same amount of stress relief was achieved by both the conventional and the high-speed process.

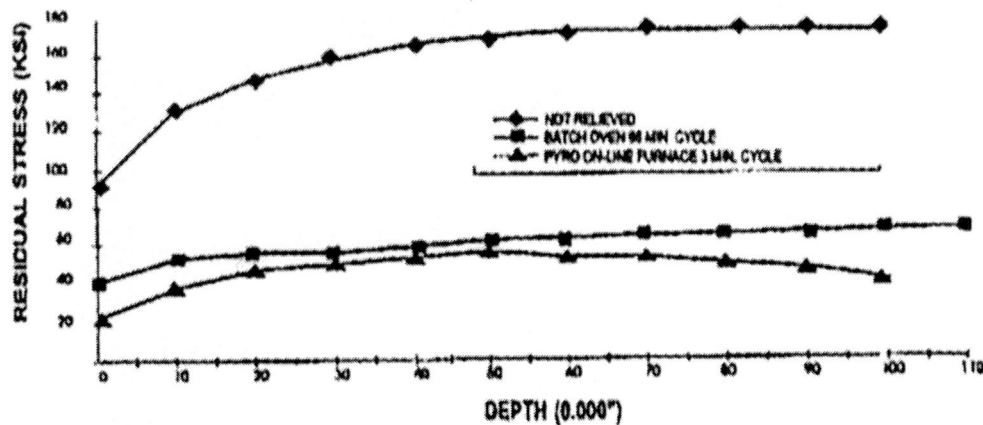


Figure 6 – Comparison of x-ray residual stress measurements on automotive belt tension springs after the conventional and high-speed stress-relief process.

Currently, various high-speed tempering processes have been successfully developed using Pyro ovens. These include automotive axles, hypoid gears and CV joints.

CONCLUSIONS

In this paper, an overview of the metallurgy of stress-relieving and tempering has been provided. This discussion included a brief review of methodologies used at the present time to calculate stress-relief and tempering times. It was shown that although soaking times and temperatures were generally fixed by the steel chemistry, substantial reductions in process times can be achieved by accelerating the heat-up time by designing more efficient heat transfer between the heated atmosphere and the load by using high-speed convective, turbulent flow which also provides for significant improvements in temperature uniformity throughout the load. The use of a heat transfer simulation (Pyrograph) to facilitate the process design process was described. Also described was the development of a new bath try-out oven which successfully models any in-line continuous process. Selected example illustrating successful high-speed stress relief were also provided. From this discussion, it is clear that substantial process design efficiency and property improvements which utilize less floor space and provide for greater production productivity are possible using a high-speed stress relief or tempering process.

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